Investigation of New Special Deoxidizers

by C. G. Mickelson

THE ultimate goal in the steel casting industry is to produce a product which will have the most desirable physical properties and be sound and free from pinhole porosity and other known defects. At the present time the use of aluminum in most grades of cast steel is necessary to completely eliminate any difficulties which might result from pinhole porosity. There are, of course, exceptions to this rule and certain grades of steel or certain types of castings can possibly be produced without the use of aluminum. There are times that when only aluminum is added certain physical properties are not as satisfactory as when other additions are used with the aluminum or in place of it.

In an investigation of numerous types of deoxidizers it has been found that some produce excellent results while others are of little value. This paper will merely touch on four of these special additions.

When aluminum was used as a deoxidizing agent it was observed that certain heats did not have the best ductility properties desired for specific types of products. The use of the proper amount of aluminum resulted in the formation of crystalline or Type 3 inclusions which produced satisfactory physical properties for certain grades of steel. The high tensile steel requiring 60,000 psi yield, 90,000 psi tensile, 22 pct elongation and 45 pct reduction of area is one of these grades. For certain specifications the yield and tensile properties remain the same but the elongation and reduction of area are increased to 25 and 50 pct, respectively. For such specifications low ductilities are occasionally experienced on a definite percentage of the heats. This condition is considerably aggravated and more pronounced in acid practice where the sulphur contents are somewhat higher. It is known from past experiences that the round type of inclusions are the most desirable for obtaining high ductility properties. Considerable information has been pre-

sented by a number of investigators, especially by Mr. A. P. Gagnebne,¹ regarding the use of selenium. This element might well be used for obtaining the desired round inclusions and the desired high physical properties. In some previous work it was observed that selenium used alone would not eliminate pinhole porosity on normal grades of steel as determined by our porosity test casting and X-ray examination. The porosity test casting consists of a flat plate approximately $\frac{7}{8}$ in. in thickness, 6 in. wide and 7 in. long. It is gated in one corner, with a pop riser located on the opposite corner. Because selenium does not eliminate pinhole porosity it was decided to use this element in conjunction with varying amounts of aluminum. The aluminum was added to control the porosity while the selenium was used to control the type of inclusions. In the initial laboratory investigations, split heats were produced in the induction furnace with varying aluminum additions made to the first part of the heat and varying amounts of aluminum and selenium added to the second part of the heat. Table I illustrates the average results which were obtained after standard heat treatment. It can be noted that the ductility properties improved when the proper amount of selenium was added to the steel. In the metallographic investigation it was found that when the proper addition of selenium was added to the steel containing either $\frac{1}{2}$ lb or 2 lb of aluminum per ton of charge the inclusions were changed from the elongated or crystalline type to the round type.

Table I—Comparison of Physical Properties of High Tensile Steel With and Without the Selenium Addition

Heat	Deoxidizer Per Ton	Yield, Psi	Tensile, Psi	Elong., Pct	Red. Area Pct
1	0.5 lb Al	65,100	93,000	25.5	42.6
	+0.05 pct Se	69,900	94,100	27.6	50.3
2	0.5 lb Al	65,400	90,600	25.6	39.4
	+0.15 pct Se	64,500	88,400	29.2	53.9
3	0.5 lb Al	72,800	95,700	25.3	41.3
	+0.30 pct Se	68,400	90,300	27.9	48.8
4	0.5 lb Al	65,600	91,300	26.3	43.3
	+0.50 pct Se	64,200	87,400	27.0	48.7
5	2 lb Al	64,600	91,100	27.8	49.3
	+0.05 pct Se	67,200	91,800	27.8	46.8
6	2 lb Al	67,100	95,300	27.0	50.8
	+0.15 pct Se	67,000	94,100	28.0	51.9
7	2 lb Al	66,000	94,800	26.8	50.9
	+0.30 pct Se	64,700	90,200	28.8	52.2
8	2 lb Al	65,000	92,100	28.6	53.5
	+0.50 pct Se	64,600	90,000	29.2	52.2

Additional experiments were made, using $1\frac{1}{2}$ lb of aluminum with selenium additions varying between 0.075 pct and 0.10 pct. In these heats excellent results were obtained. The average physical properties ranged approximately 66,000 psi yield, 101,000 psi tensile, 26 pct elongation and 54 pct reduction of area.

With these promising results, experiments were tried in the acid electric shops and satisfactory ductility properties were obtained. The ductility results were considerably above those normally obtained on a similar grade of steel treated only with aluminum.

It was noted in one of the shops that when the scrap from these selenium heats was kept segregated and used over and over again with additional selenium added, a buildup of selenium resulted. This buildup of selenium seemed to reduce the fluidity properties of the steel. However,

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if the selenium addition would be added to only a few heats per day and the scrap from these heats would not be segregated, no difficulties regarding pouring would be encountered. At one of the shops this addition of selenium is now being used as standard practice in the production of premium types of work. The high cost prohibits its use on all heats but it can economically be used on special specification work.

Graphidox

In the high tensile steel, which requires meeting 60,000 psi yield, 90,000 psi tensile, 22 pct elongation and 45 pct reduction of area, some difficulty was encountered when a change was made from the practice of using 5 lb of high carbon ferrotitanium per ton of charge to the practice of using 2½ lb of aluminum per ton of charge. This change was made in order to improve the general practice and produce castings completely free of pinhole porosity. Satisfactory results were obtained under laboratory conditions but from time to time in the shop certain difficulties occurred. One difficulty was that on a certain percentage of the heats lower reduction of area properties were obtained than when titanium was used. This lower reduction of area was due to the presence of some elongated inclusions. In addition it was found that a more rapid cooling from the molten state was conducive to the formation of elongated inclusions. This was observed where either chilled molds were used or where very light sections were poured.

Another problem encountered was the lower yield point obtained with the aluminum treated

Table II—Comparison of Physical Properties from Split Heats Deoxidized with Aluminum and Aluminum Plus Graphidox

Heat	Deoxidizer Per Ton, Lb	Temp., °F	Yield, Psi	Tensile, Psi	Elong., Pct	Red. Area, Pct	Charpy, Ft-Lb
1	Al—2½	950	66,400	96,700	26.4	52.1	50.6
		1050	64,100	95,700	26.6	50.9	49.4
	Al—2½	950	70,000	100,200	26.5	52.2	47.8
		1050	69,100	99,000	26.4	50.9	49.4
2	Al—1¼	950	69,100	102,200	24.9	50.1	48.9
		1050	68,200	100,500	26.0	53.2	46.0
	Al—1¼	950	73,300	104,200	24.0	48.6	46.0
		1050	73,100	102,900	25.6	50.5	42.2
3	Al—5⁄₈	950	68,100	101,600	22.0	38.1	33.4
		1050	67,000	100,100	21.2	38.4	31.3
	Al—5⁄₈	950	73,600	104,800	25.4	52.2	46.5
		1050	72,600	102,900	25.4	50.7	42.0

steel. This was especially critical when bars were attached to castings and cooled in large heat treating furnace loads.

In an effort to correct these two conditions, research investigations were conducted using two different materials—one called Graphidox and the other calcium-manganese-silicon. Most people are familiar with the calcium-manganese-silicon alloy addition as a number of papers have been presented on this subject. Graphidox is an alloy containing 6 pct calcium, 50 pct silicon and 10 pct titanium. Again split heats were produced using the regular aluminum addition of 2½ lb per ton. Other heats were made with smaller additions of aluminum so as to vary the types of inclusions obtained. In the second half of the aluminum treated heats, 3 lb of Graphidox or 3 lb of calcium-manganese-silicon was used in addition to the aluminum. The general analyses of the steel used in this investigation contained 0.31

Table III—Comparison of Physical Properties from Split Heats Deoxidized with Aluminum and Aluminum Plus Ca-Mn-Si

Heat	Deoxidizer Per Ton, Lb	Temp., °F	Yield, Psi	Tensile, Psi	Elong., Pct	Red. Area, Pct	Charpy, Ft-Lb
4	Al—2½	950	68,900	102,700	24.4	49.7	44.3
		1050	67,900	100,100	25.1	51.3	43.3
	Al—2½	950	71,200	105,500	25.2	52.9	44.3
		1050	67,300	103,000	25.4	51.5	43.1
5	Al—1¼	950	66,300	94,400	26.4	52.2	47.9
		1050	63,300	91,400	27.4	51.7	49.0
	Al—1¼	950	66,500	96,700	27.7	56.2	62.7
		1050	64,100	93,700	28.8	57.2	60.0
6	Al—5⁄₈	950	71,100	104,900	20.4	39.5	34.5
		1050	70,900	101,800	21.4	39.4	32.2
	Al—5⁄₈	950	70,600	105,300	24.9	52.0	44.4
		1050	69,500	101,800	25.1	52.0	43.4

pct carbon, 1.65 pct manganese, 45 pct silicon, 0.015 pct phosphorus and 0.035 pct sulphur. Average results of this work can be seen in Tables II and III. It is interesting to note that the average increase in the yield point was approximately 4800 psi when Graphidox was added to the aluminum treated steel and only 500 psi when calcium-manganese-silicon was added to a similar aluminum treated steel. In other words, the Graphidox addition definitely helped to improve the low yield properties which were causing plant troubles.

Both special additions improved the inclusions and physical properties of the steels containing 5⁄₈ lb of aluminum per ton. When this amount of aluminum was added elongated inclusions were obtained; however, when Graphidox or calcium-manganese-silicon was added the elongated inclusions were transformed to the crystalline type. Further work on this subject was performed, showing that the Graphidox addition could be added either before or after the 5⁄₈ lb of aluminum addition and still change the elongated inclusions to the crystalline type. Results of this comparison can be seen in Table IV.

Plant experiments indicated similar and encouraging results under production conditions.

Silicon-Magnesium-Aluminum

It has always been found desirable to stock as few items as possible and to make only the minimum number of additions to the molten steel. It is believed that the minimum number of additions made to the molten metal will not only produce a better grade of steel but will produce it at a reduction in cost.

An alloy containing approximately 40 pct silicon, 7.5 pct magnesium and 3.5 pct aluminum was submitted for consideration as an addition which could replace the 50 pct ferrosilicon, the aluminum and the calcium-manganese-silicon additions. If this material could be used it would be necessary to stock only one item instead of three, to weigh only one material, and to make only one addition to the molten metal. To investigate this material, grade B and high tensile steels were produced in the laboratory induction furnace. The grade B steel analyzed about 0.26 pct

Table IV—Comparison of Physical Properties of High Tensile Steel Treated with Graphidox

Heat	Yield, Psi	Tensile, Psi	Elong., Pct	Red. Area, Pct	Charpy, Ft-Lb
A	73,700	104,500	25.0	52.6	45.5
B	72,600	103,900	25.6	52.5	47.3

A—Graphidox before aluminum, B—Graphidox after Aluminum

carbon, 0.70 pct manganese, 0.45 pct silicon, 0.015 pct phosphorus and 0.035 pct sulphur. The high tensile heats averaged about 0.31 pct carbon and 1.65 pct manganese with the other elements being the same as grade B. All heats were melted in a similar manner except that the residual silicons in both grades of steels were varied from 0.01 to 0.40 pct. This variation in the residual silicon content allowed for deviations in the special alloy additions.

In a basic melting practice normally a 0.01 pct residual silicon would be obtained. However, in an acid melting practice the residuals in silicon could vary up to 0.40 pct, depending upon the temperature at which the metal was tapped from the furnace. A high residual silicon would necessitate the use of less special alloy, which in turn would lower the amount of aluminum and magnesium added. A condition like this would cause difficulties both in porosity and in inclusions. The steel from the heats produced was poured into standard test block molds and porosity test plates. Fig. 1 illustrates the condition of the porosity test plate when properly deoxidized with aluminum. Note the complete absence of pinhole porosity. Fig. 2 represents a similar plate, except that in this case only silicon was used as a deoxidizer. Note the extreme amount of porosity that can be obtained in this test casting. It has been found that the amount of porosity in this plate will depend upon the type of steel, the strength and quantity of the deoxidizer used.

It was observed on both grades of steel in this experiment that the special deoxidizer completely eliminated pinhole porosity when the residual silicon was 0.10 pct or less. In both grades of steel when the residual silicon was 0.20 pct a slight amount of porosity was observed in the test plates. When the residual silicons were increased to 0.30 and 0.40 pct considerable porosity was observed. There was no doubt that insufficient aluminum and magnesium were added to completely deoxidize the steel when the silicon residuals were about 0.20 pct.

A similar correlation was noted in the ductility properties of the pull bars. Table V compares physical property results of both grades of steel at the various residual silicon levels. When the residual silicon contents reached 0.20 pct a detrimental change took place. At this point the reduction of area of the grade B steel dropped from 51 to 46 pct while the reduction of area of the high tensile steel dropped from 50 to 34 pct. The examination of these bars with the 0.20 pct residual silicon showed that the inclusions were elongated or partly elongated instead of crystalline as was observed in the heats with a 0.01 and 0.10 pct silicon residual. In other words, with a 0.20 pct residual silicon the amount of aluminum and magnesium added was insufficient to either eliminate the pinhole porosity or to produce the correct type of inclusions.

When the silicon residuals were at a higher level insufficient aluminum was added to have any effect on the inclusions with the result that they were round as normally obtained when no special deoxidizers were added. Excellent ductility properties were obtained but the castings could not be classed as free of porosity.

This laboratory study indicated that the special deoxidizer investigated would be satisfactory

Fig. 1—(Left) Exograph of porosity test plate using aluminum treated steel.

Fig. 2—(Right) Exograph of porosity test plate using steel with no special deoxidizer.

for use in basic practice where residual silicons are lower. It was found that the magnesium caused considerable pyrotechnics which would be objectionable. In order to remain on the safe side it was recommended that the aluminum content be increased and the magnesium content decreased. There is no doubt that this deoxidizer exhibits considerable promise and further work is contemplated.

Sodium

Sodium is one of the newer additions to steel which has aroused the curiosity of numerous investigators regarding its effect on sulphur reduction and deoxidization properties. A number of grade B and 0.45 pct carbon steel heats were produced in order to study its effect when added to liquid steel. Split heats were again used for comparison purposes. In some cases no special deoxidizers were added to the first half of the heat and sodium additions, as metallic sodium or as sodium emulsion in kerosene, were made to the second half of the heat. In all of the heats produced the sulphur, in the second half of the heats where the sodium addition was made, remained the same or was only reduced one point. Thus, it appears that under induction furnace melting the sodium addition made to the stream as it enters the ladle has no significant effect on sulphur reduction. There is a possibility that in large furnaces this condition might not be true. It should be added at this point that considerable sparking occurred when the sodium metal

Table V—Effect of Variations in Residual Silicon on the Physical Properties and Porosity Results of Steels Deoxidized with Si-Mg-Al Alloy

Steel	Residual Silicon	Porosity Results	Yield, Psi	Tensile, Psi	Elong., Pct	Red. Area, Pct
1	0.01	OK	48,400	75,600	30.3	51.2
1	0.10	OK	46,500	76,400	31.0	51.8
1	0.20	Some	49,000	79,000	29.3	46.8
1	0.30	Porosity	42,400	75,600	32.4	57.7
1	0.40	Porosity	45,100	78,300	33.5	57.7
2	0.01	OK	67,100	100,500	24.5	48.5
2	0.10	OK	67,600	99,100	26.2	51.3
2	0.20	Some	64,600	101,700	19.6	34.4
2	0.30	Porosity	65,400	104,700	20.8	40.2
2	0.40	Porosity	65,200	98,100	26.2	54.2

1—Grade B, 2—High Tensile

was added while very little sputtering occurred when the sodium emulsion was used. In the latter case a large amount of dense fumes were evolved due to the burning of the kerosene.

When the sodium was added in the emulsion form to grade B and 0.45 pct carbon steel it did not deoxidize the steel sufficiently to eliminate pinhole porosity as determined by our porosity test casting. The 1 lb of sodium added as sodium emulsion produced a test casting which was identical with respect to porosity as one poured in the first half of the heat where no sodium or special deoxidizer was added. This condition was found to be true in both grades of steel investigated. When 1 lb of metallic sodium per ton of charge was used pinhole porosity for all practical purposes was eliminated. This condition again was found to be true for both grades of steel under study. Thus it is our feeling that metallic sodium is a powerful deoxidizer.

Table VI—Comparison of Physical Properties of Steel Produced With and Without Sodium

Heat	Deoxidizer Per Ton, Lb	Yield, Psi	Tensile, Psi	Elong., Pct	Area, Pct	Charpy, 70 F	Ft.-Lb —40 F
1	Al—2½ Graphidox-3	50,000	75,500	29.0	45.7	40.5	15.0
1	Al—2½ Graphidox-3	49,800	77,600	30.5	51.6	38.0	17.5
2	Na Emulsion-1	51,000	94,600	24.7	45.0	20.0	3.3
2	None	51,000	90,400	19.2	25.5	14.8	6.3
2	Na Metal-1						

1—Grade B Steel, 2—0.45 Pct Carbon Steel

In checking the physical properties of a few of the heats which were produced it was found that in the 0.45 pct carbon steel 1 lb of metallic sodium produced a metal with poor ductility properties. This was due to the fact that elongated inclusions were formed. When the sodium emulsion was used in conjunction with a regular aluminum addition on grade B steel an improvement in ductility properties was observed over the same steel without the sodium emulsion. Table VI compares the physical properties of the steels with and without the sodium additions.

In certain respects there appeared to be considerable promise for the use of this material but more investigations will have to be performed before consistent results can be expected on a production basis. Extreme care must be exercised in storing the metallic material, handling it and making the additions.

It is hoped that this paper has presented some information and ideas that may be of help in production problems and stimulate further research and investigations on this interesting and sometimes baffling subject of deoxidization. This opportunity is taken to thank the officials of the American Steel Foundries for permission to present this information and for the personal help and guidance of Mr. G. A. Lillieqvist, Research Director.

¹A. P. Gagnebigne: Influence of Selenium on Sulfide Inclusions and Ductility of Cast Steel. *American Foundrymen's Society Transactions*, 1947.

British Report on Drop Forging

THE "Productivity Team Report; Drop Forging," based on the findings of British forging experts after a tour of 130 American drop forge shops, 70 pct of which employ less than 200 men each, points up differences in practices and techniques in the two countries. The team deprecates the insistence in Britain of high quality regardless of forging use, pointing out that on some 20 forgings, American forge plant output will total as much as 400 pct more forgings per hr than British output.

In suggesting changes in British methods, the team recommended that the program be divided into two parts. Short-term and long-term policies were made, offering several recommendations. The short-term program should embrace maximum machine utilization; better cooperation on ideas and methods between forge plants; and better plant housekeeping to contribute to orderly production, raise efficiency and assist in recruiting suitable labor. Possibilities of shearing steel instead of the present practice of sawing or cutting should be studied; ventilation improved for worker comfort and efficiency; furnaces supplying hot stock should be improved and capacities increased; and descaling methods should be improved.

Larger hammers that will require fewer blows to produce a forging, result in less wear and tear on the plant and dies, and increase productivity were suggested, along with development of mechanical handling methods; a study of lubricants

to eliminate their use where possible; an increase in the use of multi-impression dies; and recommended also were a systematic maintenance program to eliminate breakdowns; systematic tool and die and maintenance part storage systems; and the use of safety goggles, clothing and other gear.

On the long-range basis, the team recommended that new plants should be more spacious and well ventilated. Spaciousness allows the manipulation of work handling equipment, reduces handling costs, and allows grouping of items of plant equipment for better work flow. High speed, high capacity equipment must be installed where replacement is necessary. Full mechanization of working handling equipment is an ideal of the program.

Better planning of plant equipment was also emphasized, it being specifically pointed out that presses in the United States were often used to set and size forgings after clipping. This eliminates the necessity of passing the clipped forging back to the hammer for setting and enables the hammerman to maintain a continuous rhythm of production. Improvement of product and development of new materials were emphasized, and the cooperation between maker and user of forgings was noted. Such cooperation often results in modifications in design that cuts costs. An educational and recruitment policy to develop skilled workers is also a vital long range policy recommended.